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EVALUATION OF MOUNTING BOLT LOADS FOR SPACE SHUTTLE GET AWAY SPECIAL (GAS) ADAPTER BEAM

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FEBRUARY 1983

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

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ILLUSTRATIONS

ILLUSTRATIONS (continued)

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1. SUMMARY

Engineering vibration tests were conducted for the Get Away Special (GAS) adapter beam and two canisters for evaluating the mounting bolts. Although 5-cubic-foot (0.142 m^3) containers were used, they were ballasted to simulate the critical configurations of the 2.5-cubic-foot (0.071 m^3) containers. Test bolts were modified to represent the critical cross-section of the flight bolts. Strain gages were also installed inside the bolts. Test items were subjected to Z-axis transient acceleration time histories measured during the STS-1 launch.

Gravity compensation systems were used for relieving the effect of gravity along the Y-axis. Also, for simulating STS acceleration at liftoff, the test items were loaded in the X direction with bungee cords. Tests were performed for several gap conditions under the bolt heads. For each gap configuration, tests were carried out with different torque values covering the entire torque specifications of 100 to 825 in-lb (11.3 to 93.2 m-N) for these bolts. The test results showed that the forward bolt experienced maximum strain for all test conditions.

Stresses (calculated from measured strains) in the critical area of the bolt exceeded the static yield stress of the material during some tests. However, no yielding was observed during microscopic examination of the bolts. A comparison of the test results for no gap and varying degrees of gap under the bolt heads does not show direct relationship between gap size and strain levels in the bolts. Acceleration levels are higher with gaps, but they do not translate to higher strains since they occur at higher frequencies. The results also show that with higher torque, strains due to dynamic loading are somewhat lower. But total strain increases with higher torque since prestrain constitutes the major part of the total strain.

2. INTRODUCTION

During the prototype vibration tests of the GAS adapter beam, significant impacting of the beam at its support points was observed.[1] The impacting resulted from a 0.025-in (0.635 mm) gap under the bolt heads. This gap is provided for control of proper load transfer to the orbiter structure. The bolts could be subjected to unacceptable shock loads because of the impacts. The adapter beam was installed on the orbiter to carry the EVA (Extra Vehicular Activity) tool kit, weighing approximately 400 pounds (181.4 kg) for the STS-2 mission. To ensure that the loads imposed on these bolts during the STS-2 mission were acceptable, vibration tests were conducted at the Goddard Space Flight Center (GSFC) with instrumented bolts. These tests showed no evidence of yielding in these bolts because of the imposed vibration environment.[2] However, an extrapolation of these results for the GAS configuration with a weight of 1000 pounds (453.6 kg) showed stresses to be well beyond the yield strength

of the bolt material.[3] This raised concern about the adequacy of the mounting bolts for carrying the load imposed due to the 1000-pound (453.6 kg) GAS canisters. Therefore, the present study was undertaken and vibration tests were conducted with two 500-pound (226.8 kg) GAS canisters mounted on the adapter beam, using strain-gaged bolts. The objectives of the tests were to:

- Evaluate the load capability of the adapter beam mounting bolts to withstand the STS launch vibration environment.
- Determine how the gap under the volt heads affects loads imposed on the mounting bolts.
- Establish how the torque values used on the mounting bolts affect the loads imposed on them.

3. TEST CONFIGURATIONS

Vibration tests were conducted for the GAS adapter beam assembly (portside beam) with two 5-cubic-foot (0.142 m^3) containers. The canisters were ballasted to 500 pounds (226.8 kg) each, simulating the critical configurations of the 2.5 cubic-foot (0.071 m^3) containers. The test setup and hardware used were described in an earlier report.[1] A typical configuration of the GAS containers/adapter beam assembly on the orbiter structure is shown in Figure 1. Tests were basically conducted for bay 2 configuration; however, some tests were also conducted for the bay 3 configuration.

Since the prime objective of these tests was to evaluate the mounting bolts, it would have been ideal to use the flight bolts in these tests. However, flight bolts were not available and if flight bolts were used, substantial modifications with test fixture would have been necessary. Therefore, the test bolts were modified simulating the critical area of the flight bolts. The test and flight bolts are shown in Figure 2. The test bolts were heat-treated, and strain gages were installed inside them. The flight bolts are made from inconel steel having longitudinal yield and ultimate strengths of 150,000 (1034 MPa) and 185,000 (1240.9 MPa) psi,* respectively. The mounting of the forward and sill bolts on the vibration fixture is shown in Figures 3 and 4. The aft bolt mounting was similar to that of the sill bolt.

Other objectives of these tests were to evaluate the effect of torque values used on the mounting bolts and gap sizes under bolt heads on stresses in the bolts. For this purpose, tests were conducted with torque varying from 100 to 425 in-lb (11.3 to 48 m-N) for the aft and forward bolts and 200 to 825 in-lb

*Rockwell International Corporation Drawing No. V073-34012, Material Specification MB0170-076.

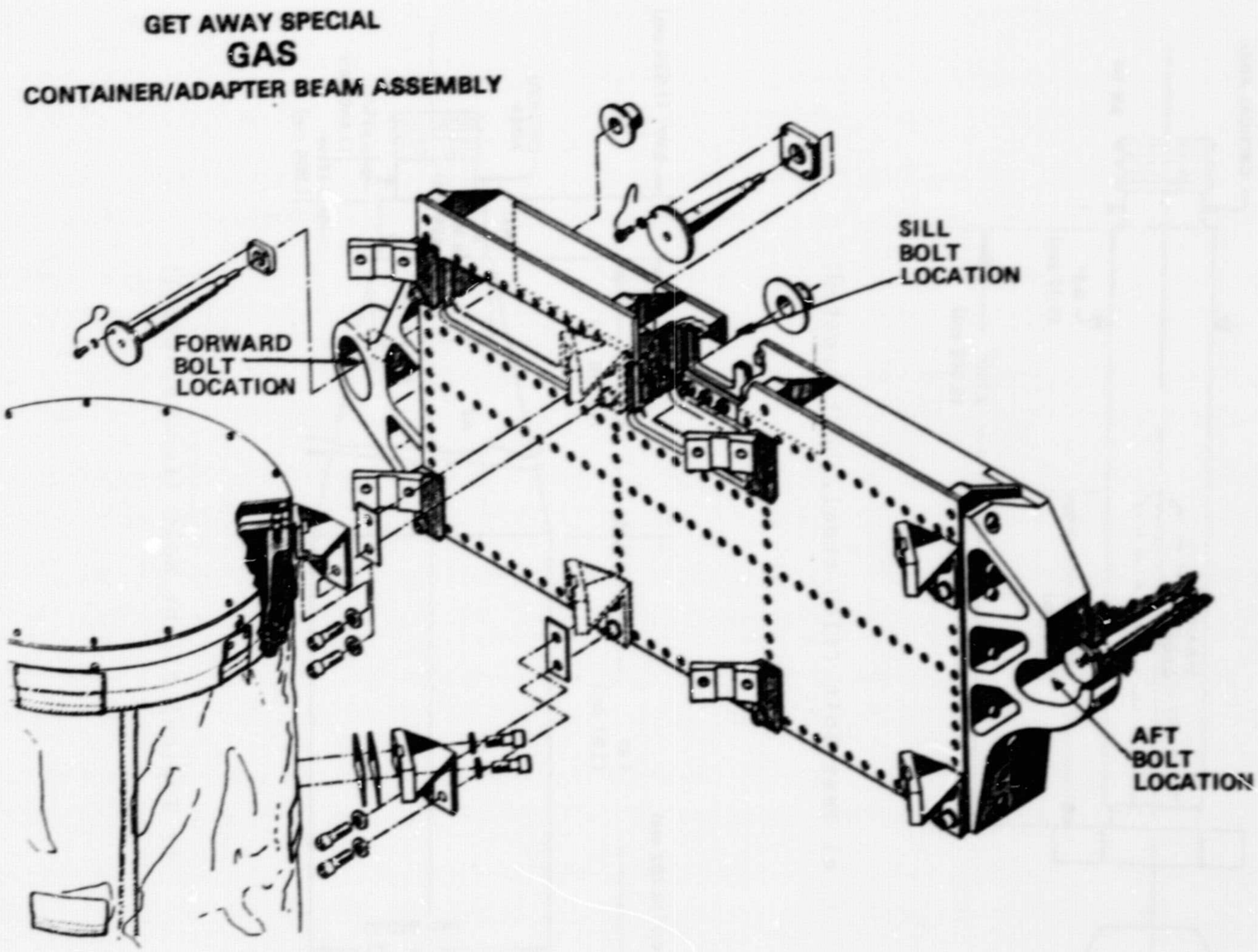
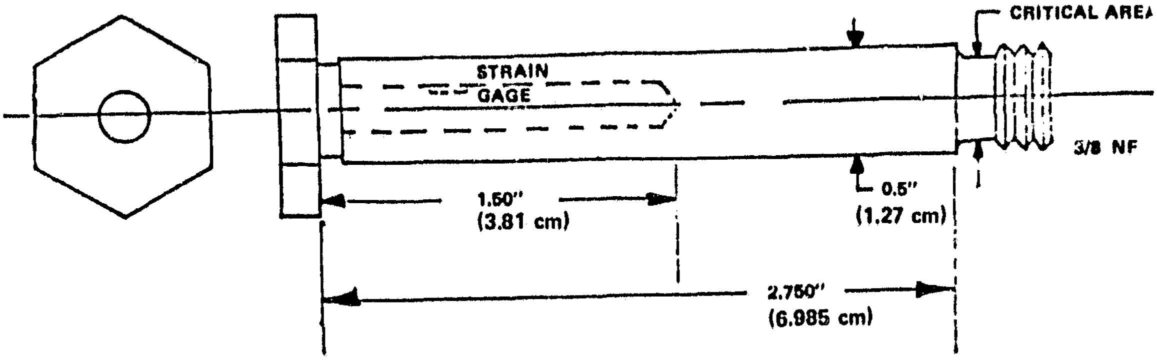
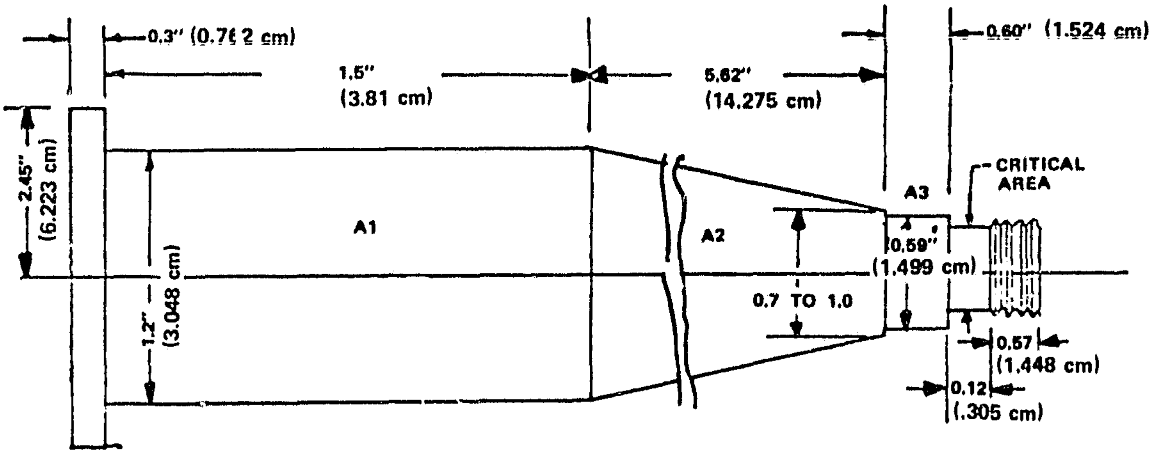


Figure 1. GAS Container/Adapter Beam Assembly



a) Test Bolt (4340 steel, heat treated)



b) Typical Flight Bolt (inconel steel)

Figure 2. Comparison of Test and Flight Mounting Bolts

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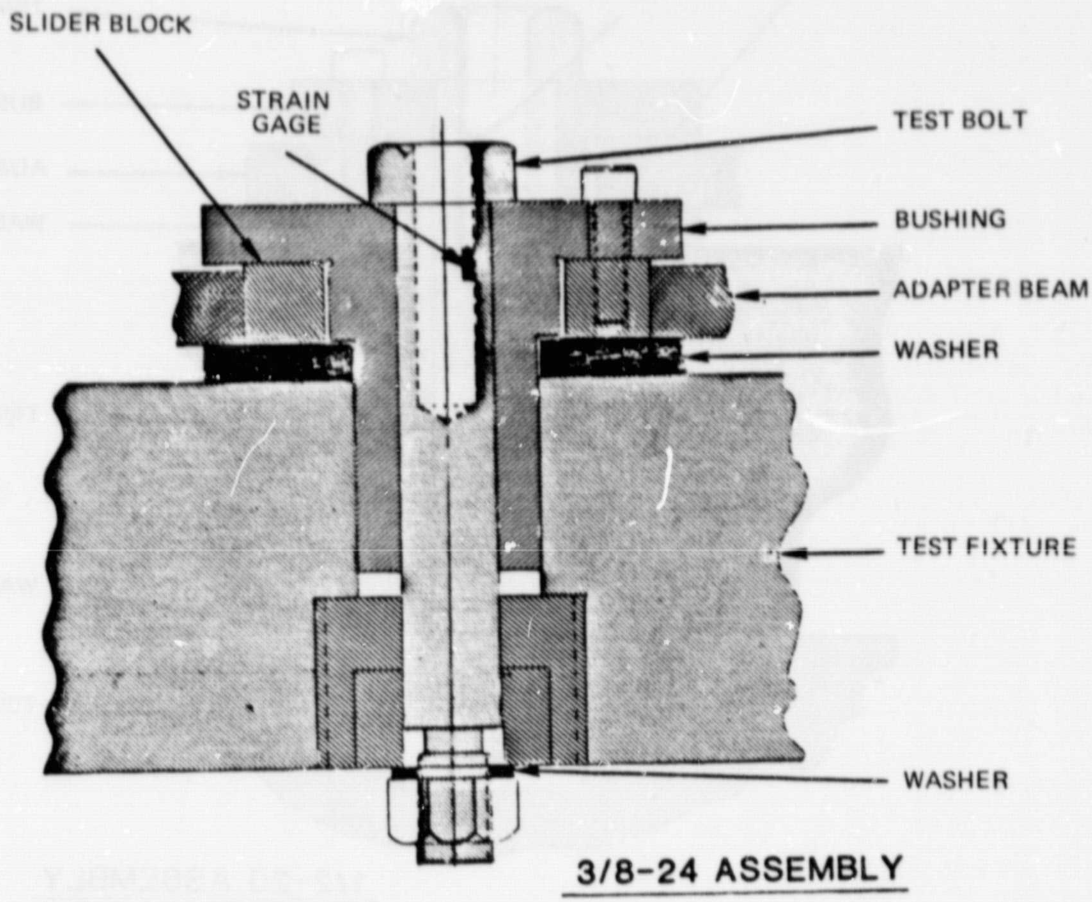

Figure 3. Forward Bolt Assembly on Vibration Fixture

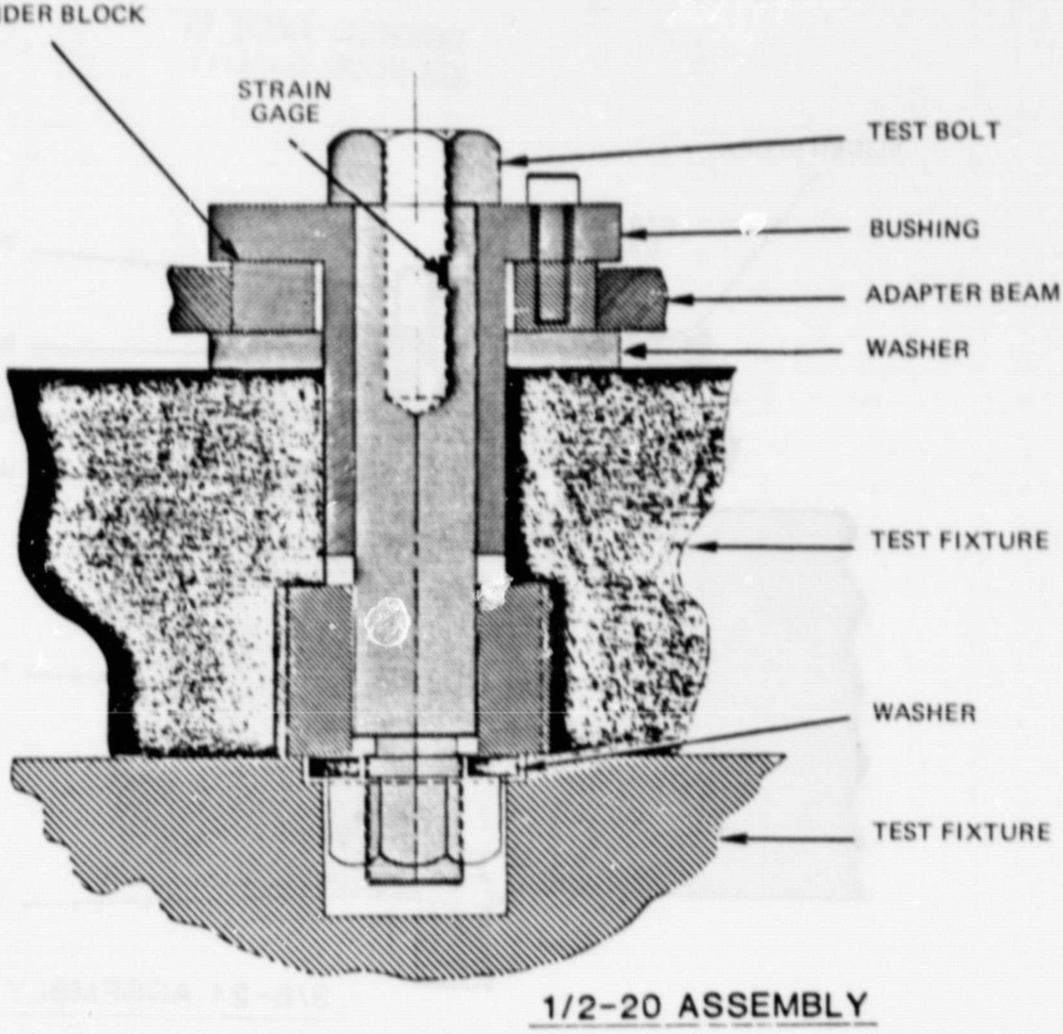

Figure 4. Sill Bolt Assembly on Vibration Fixture

(22.6 to 93.2 m-N) for the sill bolt. The gap under the bolt heads was also varied from no gap to a maximum gap of 0.025 inch (0.635 mm).

The effect of gravity acting along the Y-axis was compensated by bungee cords with 1g load of 1166 pounds (5186 N). In addition, the effect of STS acceleration in the X direction was simulated by pulling on the canisters with a 1,535-pound (6828 N) load representing an acceleration of 1.5g. This load was applied at a location above the center of gravity (c.g.) of the beam/canister system. The 1535-pound (6828 N) load is based on moment considerations. The gravity compensation systems used in these tests are shown in Figure 5.

Torque in the bracket/adapter beam and bracket/canister interface bolts were 200 and 400 in-lb (22.6 and 45.2 m-N), respectively, in these tests.

4. INSTRUMENTATION

As mentioned earlier, strain gages were installed inside the three mounting bolts. Accelerometers were also mounted on the canisters and the bolt heads (shown in Figures 6 and 7, respectively).

5. VIBRATION TESTS

5.1 TEST SPECIFICATIONS

Earlier tests on the adapter beam with simulated load for the EVA tool kit showed that the Z-axis test produced maximum bolt loads.[2] Therefore, in the present study, only Z-axis excitation was applied. The test items were subjected to transient acceleration time histories measured during STS-1 launch. The Z-axis acceleration time history, taken from the STS-1 DATE data, is shown in Figure 8.[4] In the present tests, a 12.8-second time frame (from the Z-axis accelerometer V34A9430A) including main engine ignition, SRB ignition, and liftoff was used.

5.2 BAY 2 TESTS

As mentioned earlier, the mounting bolts were modified to represent the critical area of the flight bolts, and heat treated. These strain-gaged bolts were calibrated to obtain their load/strain characteristics. A typical vibration test procedure consisted of:

- Mounting the GAS adapter beam assembly on the shaker and applying preload on bungee cord system;
- Applying suitable torque on the bolts and measuring prestrain in the bolts due to torquing;

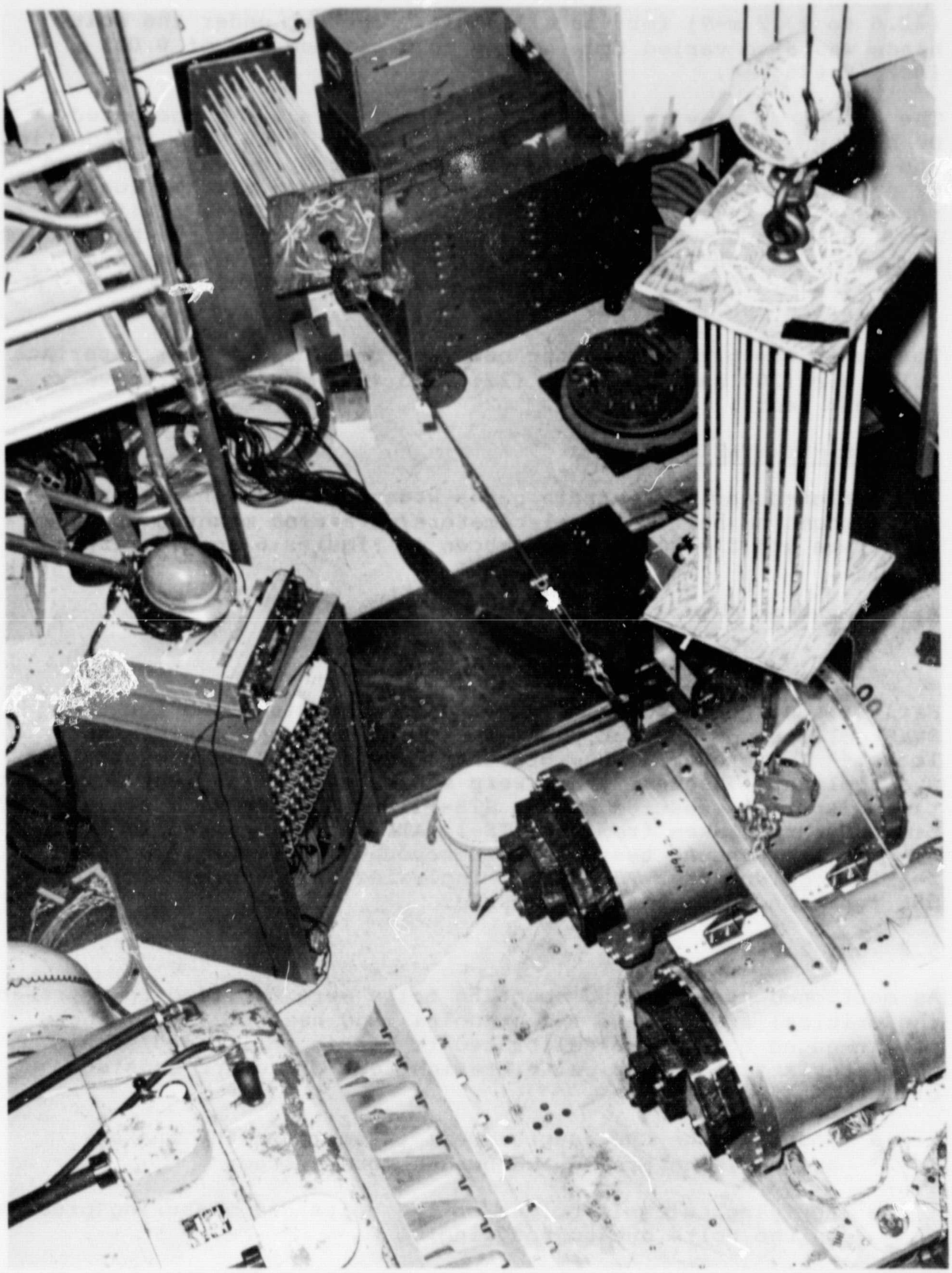

Figure 5. Gravity Compensation Systems

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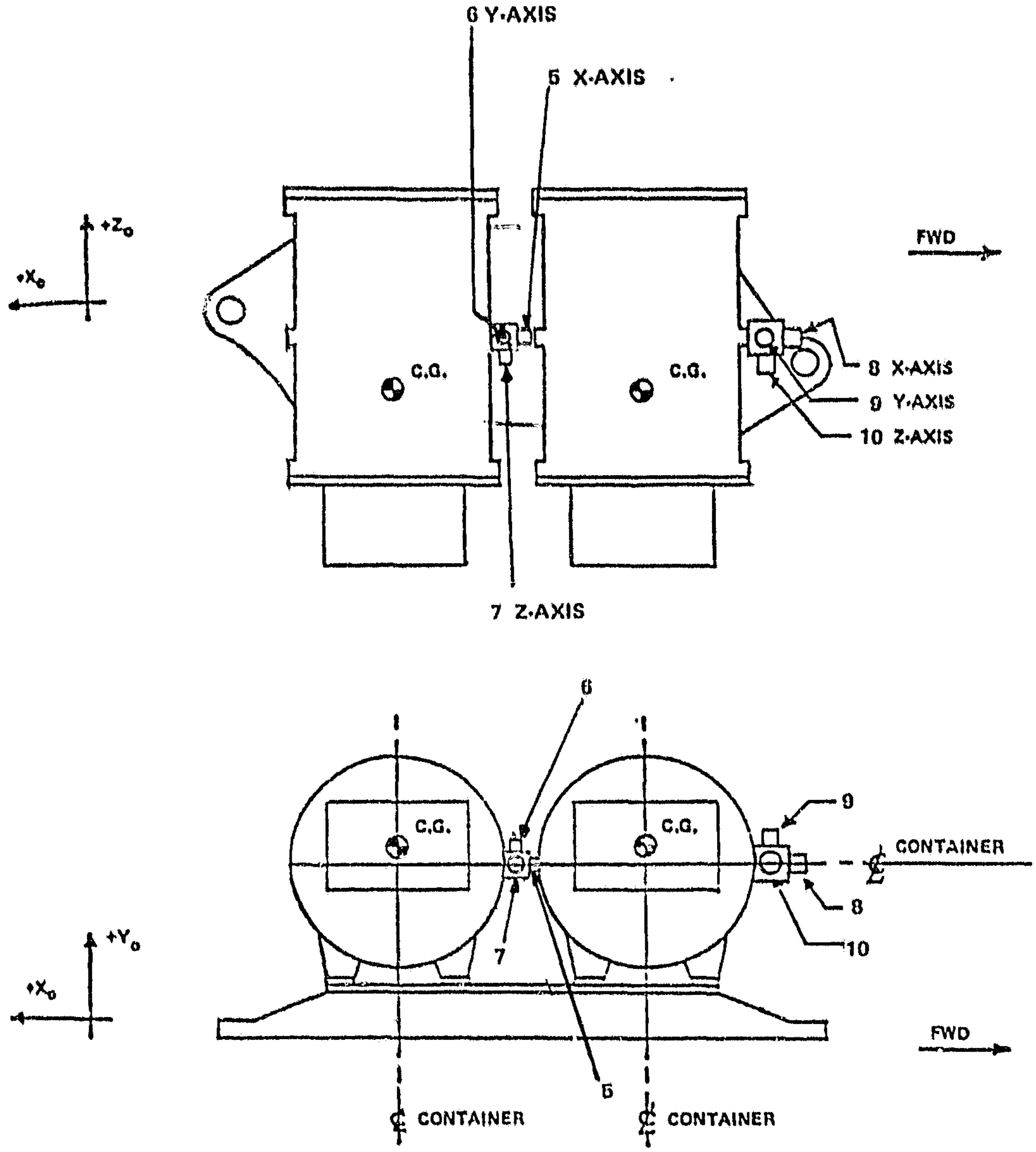

Figure 6. Locations of Accelerometers on Canisters

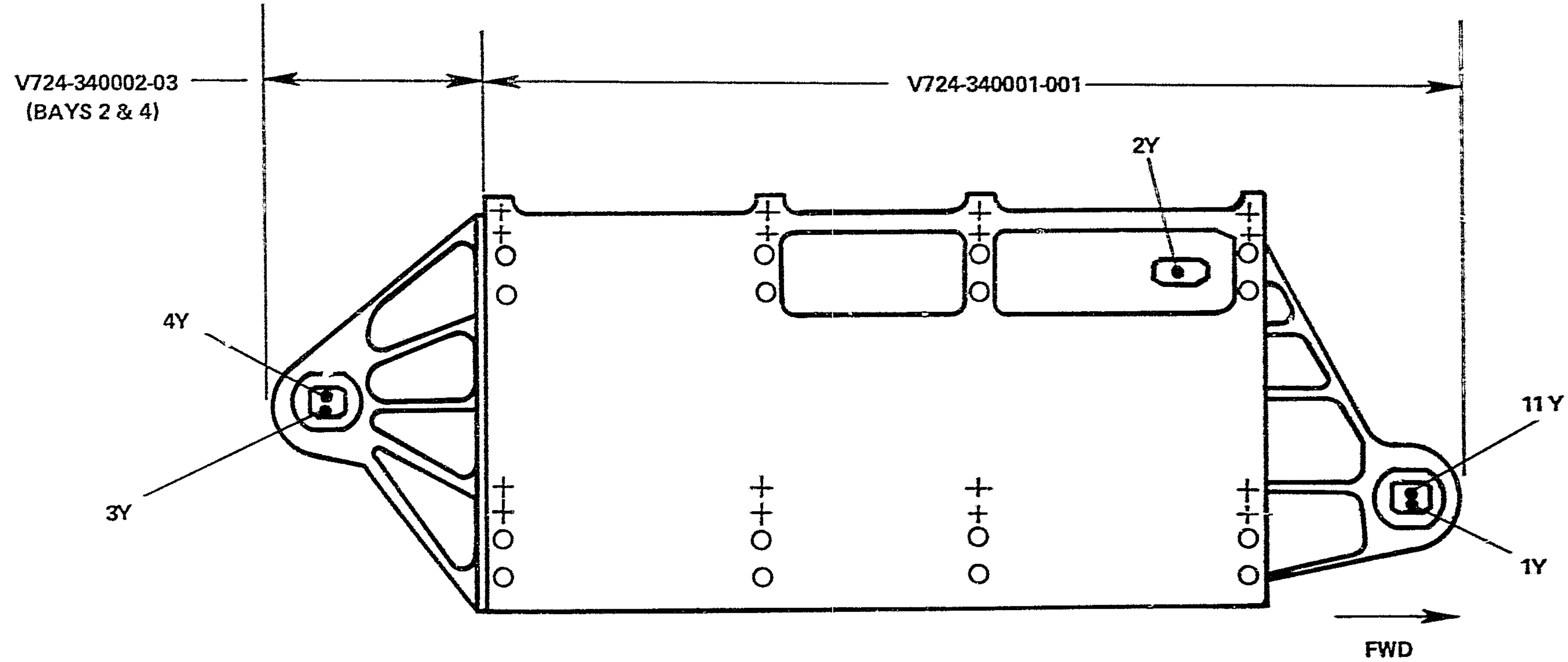

Figure 7. Locations of Accelerometers on the Bolts

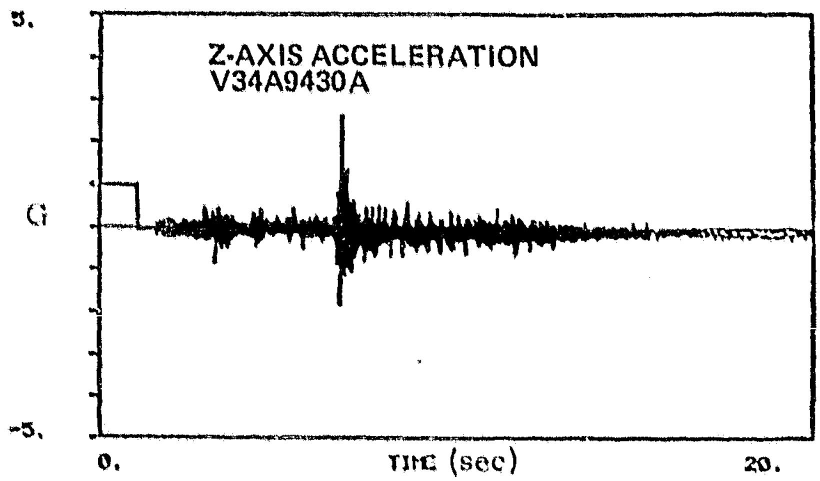

Figure 8. Z-axis Acceleration Time History (STS-1 data)

- Applying Z-axis transient waveforms (mentioned earlier) and recording strain and acceleration during the test.

Vibration tests were conducted using the transient waveform control (TWC) of the GenRad system.[5] In each test, a series of transient waveforms, starting at one-eighth of full level, was applied to the shaker using the Z-axis STS-1 accelerometer data. Initially, tests were implemented with shims (no gap) under the bolt heads. This provided a linear system response characteristic. The excitation was gradually increased to the desired test level, compensating the drive signal at each level by the most recently measured system transfer function. For tests with gap, the same drive signals as obtained with no gap were used.

Since the waveforms are unsymmetrical, both positive and negative polarity were tested. For some tests, the negative polarity produced unacceptable shaker displacement. Therefore, tests were restricted to positive polarity.

Tests were conducted for several gap dimensions (no gap, full gap, 0.010-in (0.254 mm) gap, and 0.005-in (0.127 mm) gap). For each gap configuration, tests were carried out to cover the entire torque specifications for these bolts, 100 to 825 in-lb (11.3 to 93.2 m-N).

5.3 BAY 3 TESTS

The bay 3 configuration is similar to bay 2, except that the sill bolt location is different. Tests were only conducted for no-gap and full-gap conditions for this configuration. It should be noted that for bay 3, the sill bolt was not strain-gaged or modified to conform to the critical dimension of the flight bolt. This would not affect the evaluation of the maximum loads on these bolts, since on all tests, the forward bolt experienced the highest strain.

6. RESULTS AND ANALYSIS

Using specifications and procedures previously mentioned, tests were conducted for a number of different test conditions. Data from these tests were analyzed, and time history plots for selected channels of strain and acceleration data were acquired. These time history plots were obtained for a 2-second period, encompassing the maximum response.

The strain-gaged bolts were calibrated before the test. These bolts were also calibrated after the vibration tests. A comparison of the pre- and postvibration calibration results for the second forward bolt is shown in Figure 9. It should be noted that two forward bolt were used during the vibration tests. The first forward bolt was replaced by the second one after several tests. This was done because strains obtained on the

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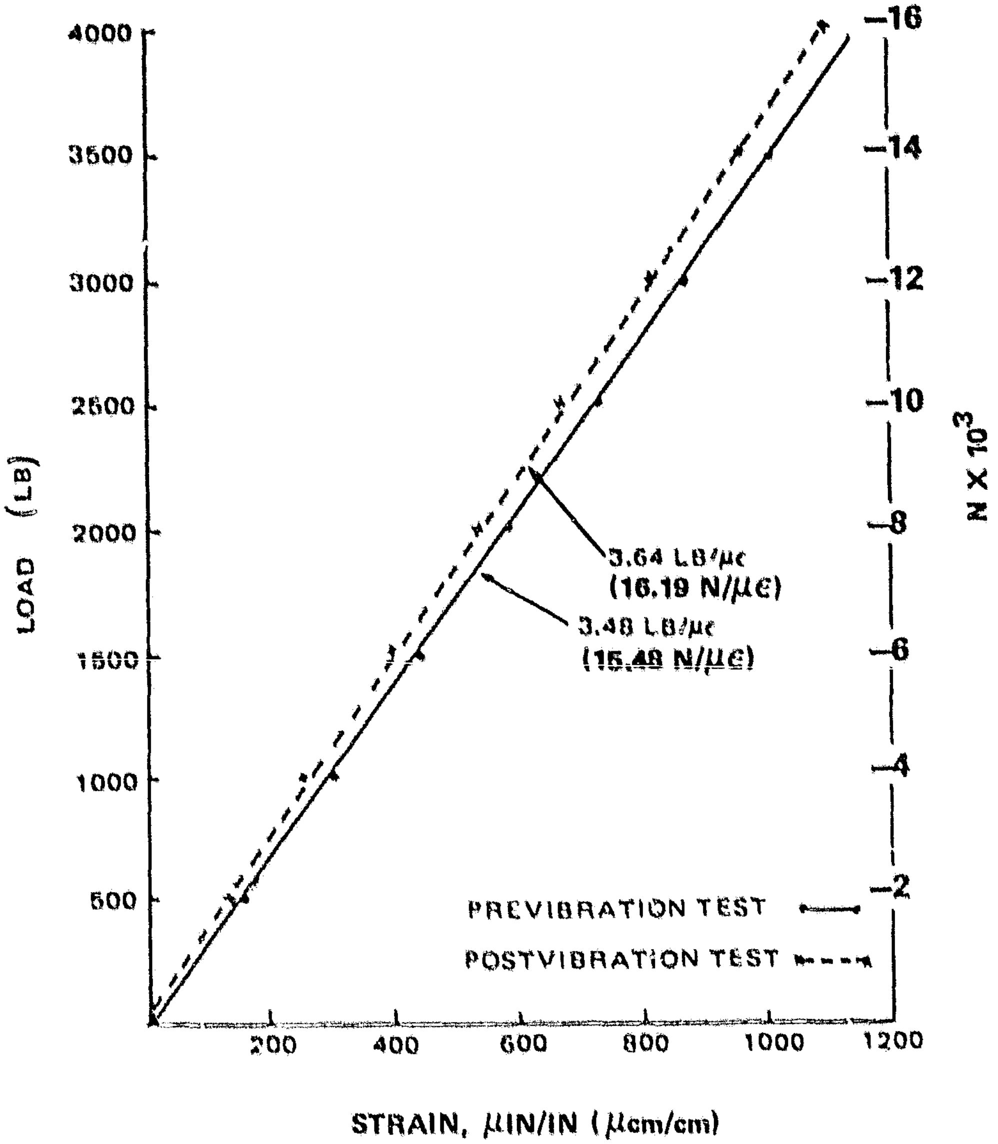

Figure 9. Comparison of Pre- and Postvibration Calibrations

first bolt due to torquing, were not very stable. This could be attributed to inconsistency in the lubrication of the bolts. However, it was felt that replacing it with a new bolt would improve the quality of the data. As seen from this figure, the load-strain characteristics are linear for the bolt. Also, the variation in the pre- and postvibration calibration results is not very significant--only around 4 percent. This indicates that strain-gage results obtained during the vibration tests should be accurate.

The test results showed that the forward bolt had the highest strain levels for all test conditions. Therefore, results are presented only for the forward bolt. However, Figures 10 and 11 display comparisons of strain levels in the three bolts for two tests runs that produced the highest levels of strain due to loading in the forward bolt.

A comparison of test results for positive and negative pulses showed the response to be higher for the negative pulse (Figure 12). A comparison of several accelerometer responses from no-gap to full-gap conditions, is shown in Figures 13 through 15. It can be observed from these figures that the accelerometer responses for no-gap conditions are of low-frequency content. This is due to low-frequency input. With gap, the frequency content is high. This is due to metal-to-metal impacting of the adapter beam at its support points.

Figures 16 through 19 show the effect of gap size. They indicate no direct relationship between gap size and strain levels in the bolt. The acceleration levels are higher with gap, but they do not translate to higher strain levels because these accelerations occur at higher frequencies. However, these higher accelerations can have an important effect on GAS payloads. The effects of torquing (prestrain) on bolt strains are depicted in Figures 20 through 23. These data show that when using higher prestrain, strain levels due to loading are somewhat lower. But, total strain is higher with higher prestrain. This is because the prestrain constitutes a major part of the total strain at higher torque levels.

Stresses at the critical area of the bolt were calculated by proportioning stresses at the gage location, in accordance with their areas. Rockwell hardness tests on the 4340 heat-treated bolt indicated ultimate and yield stresses of the bolt to be 180,000 psi (1241 MPa) and 167,000 psi (1151 MPa), respectively. For some test conditions, the stresses (calculated from measured strains) at the critical area exceeded the yield stress of the material. Visual examination of the bolts after testing did

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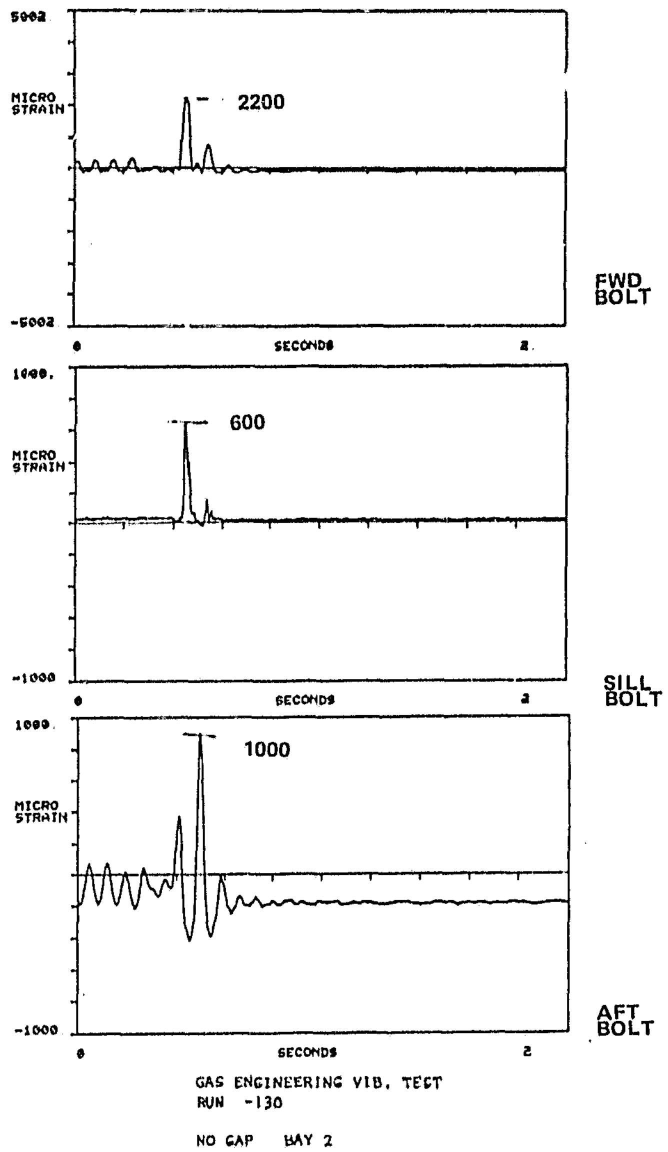


Figure 10. Comparison of Strain Responses for the Three Bolts

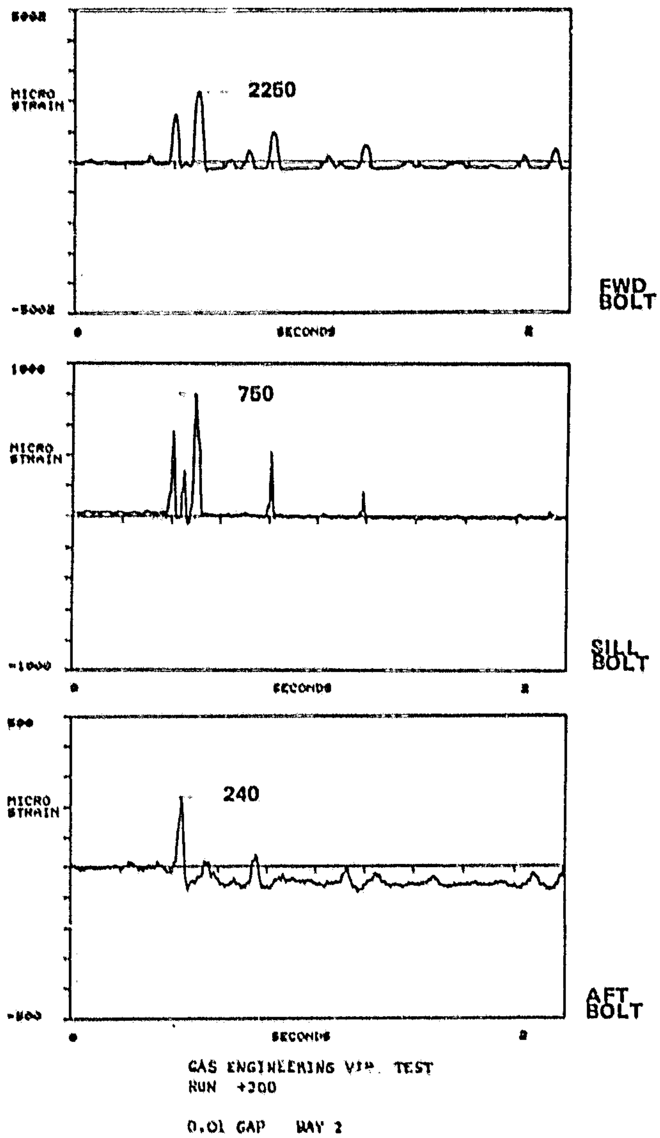
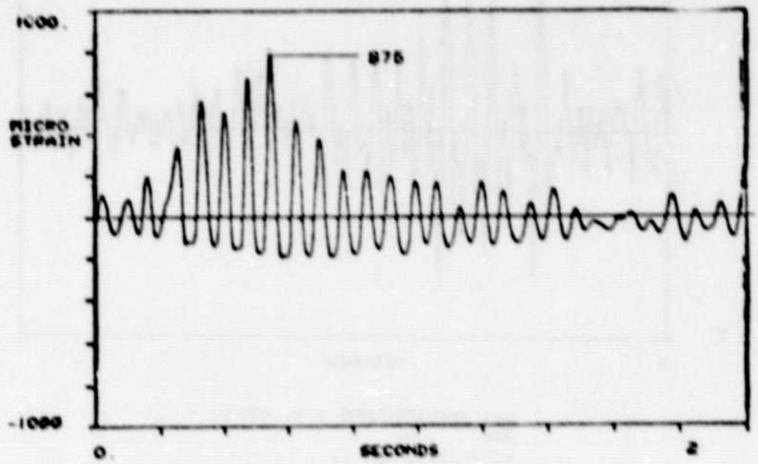
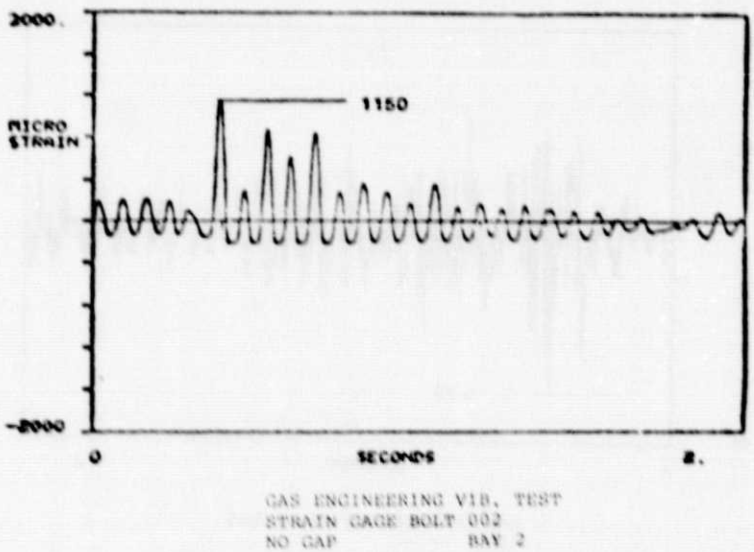


Figure 11. Comparison of Strain Responses for the Three Bolts



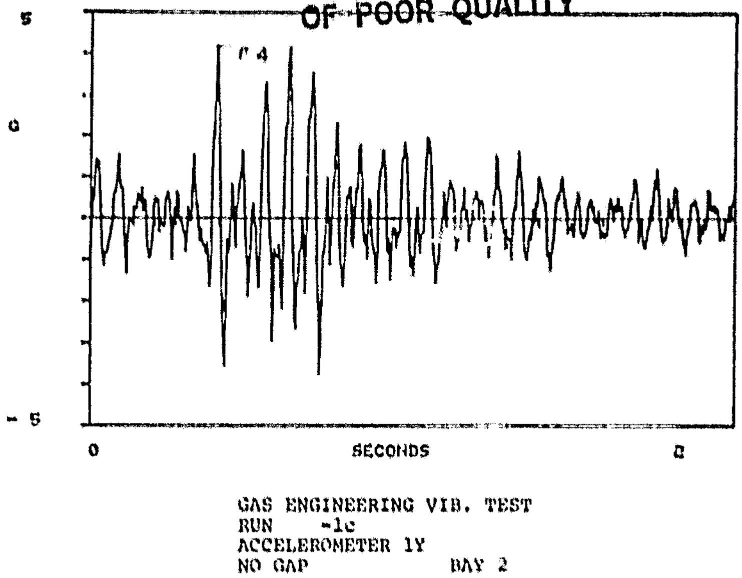
a) Run +1c (positive pulse)



b) Run -1c (negative pulse)

Figure 12. Comparison of Strain Responses for Positive and Negative Pulses

a.



b.

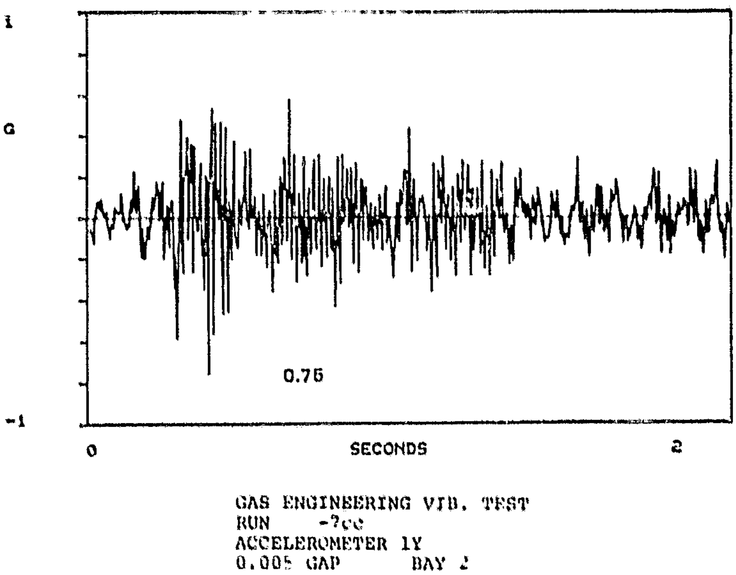
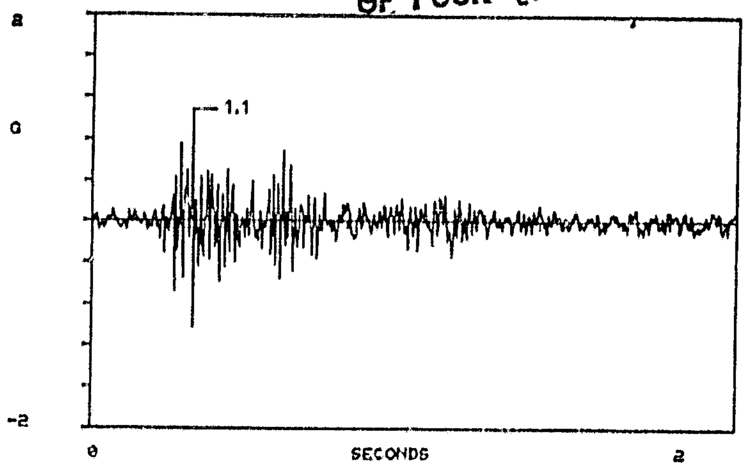


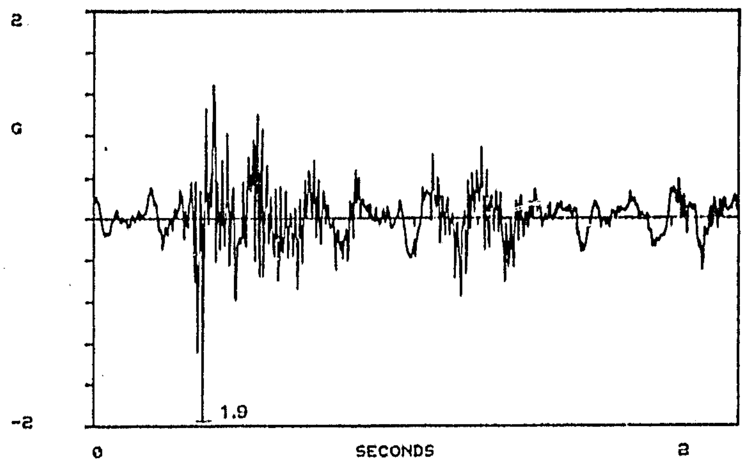
Figure 13. Acceleration Time Histories with Increasing Gap Size (Accelerometer mounted on forward bolt)

c.



GAS ENGINEERING VIB. TEST
RUN -10c
ACCELEROMETER 1Y
0.01 GAP BAY 2

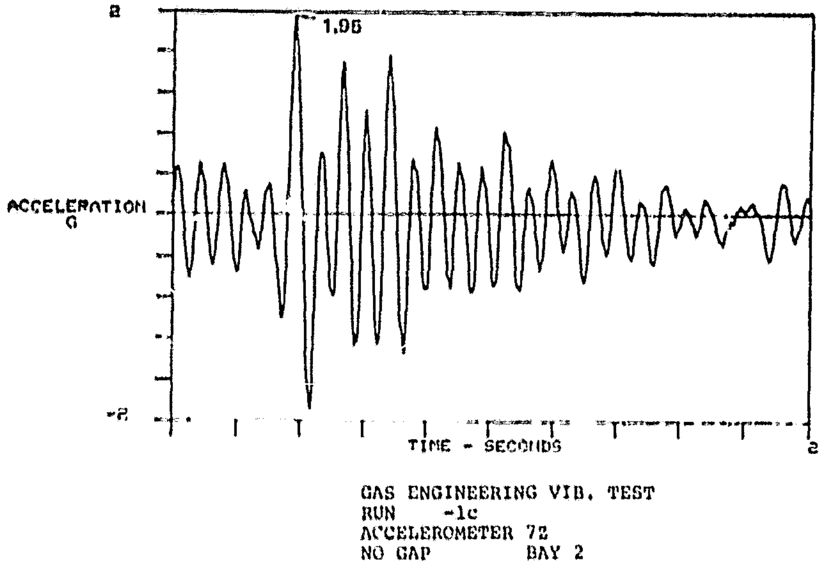
d.



GAS ENGINEERING VIB. TEST
RUN -4c
ACCELEROMETER 1Y
NO SHIMS BAY 2

Figure 13. (continued)

a.



b.

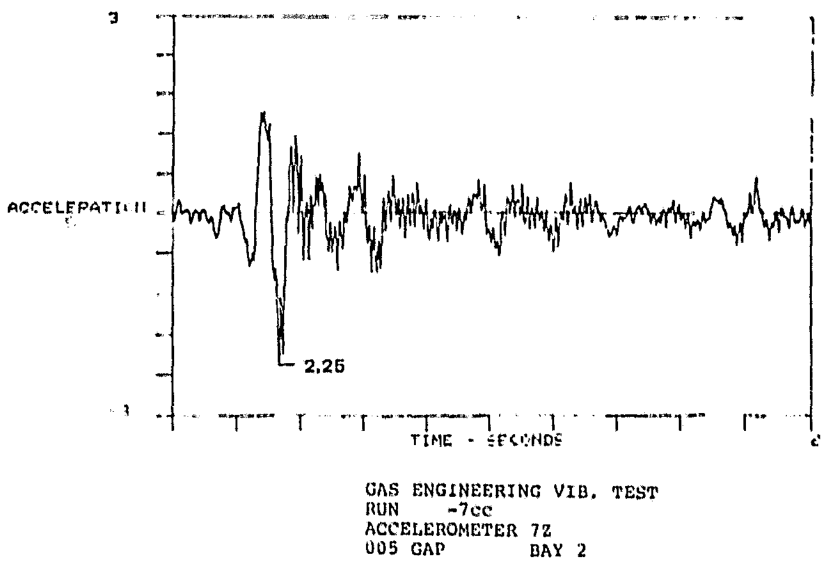


Figure 14. Acceleration Time Histories with Increasing Gap Size (Accelerometer mounted on canister).

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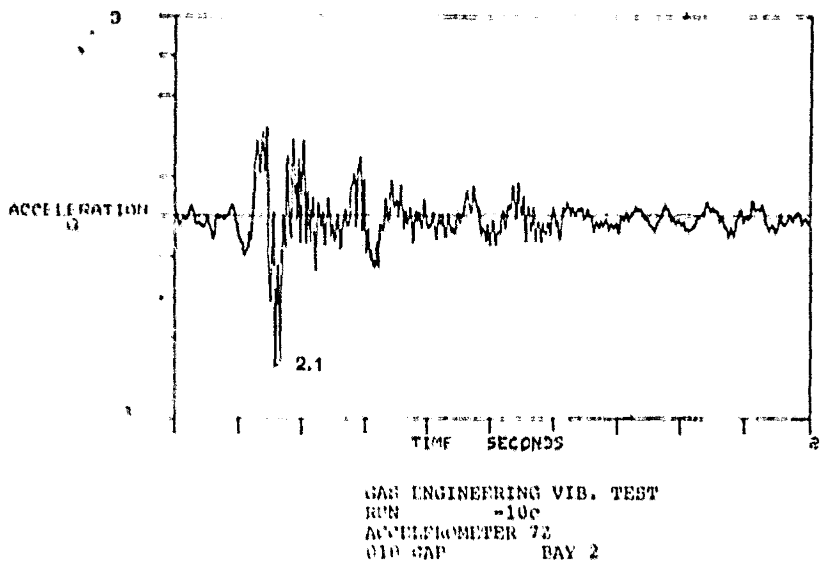
c.



d.

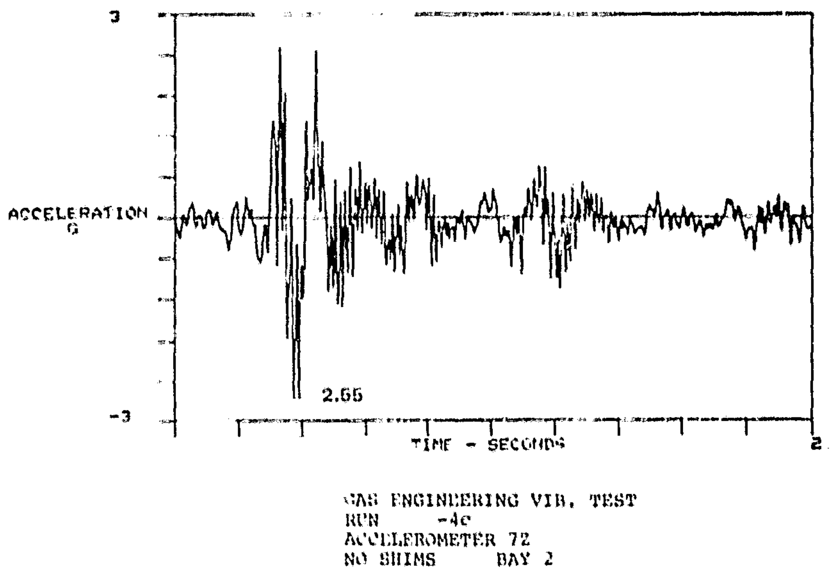
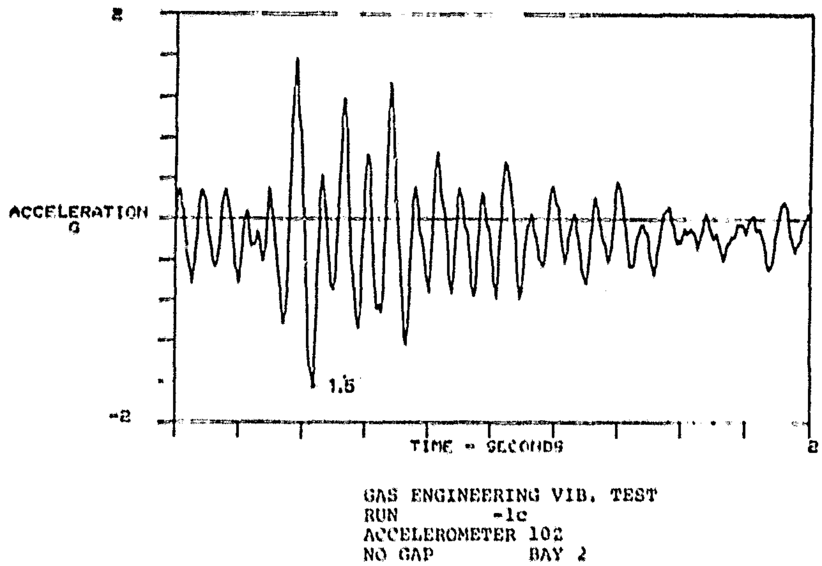


Figure 14. (continued)

a.



b.

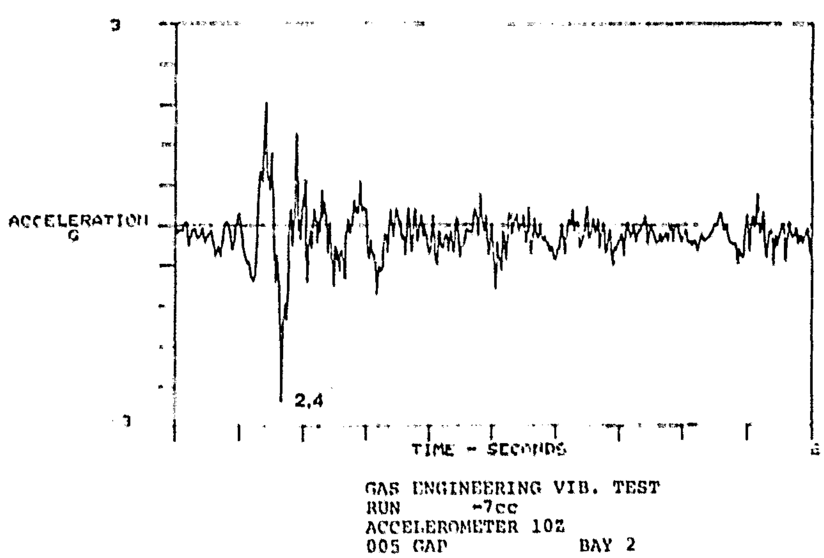
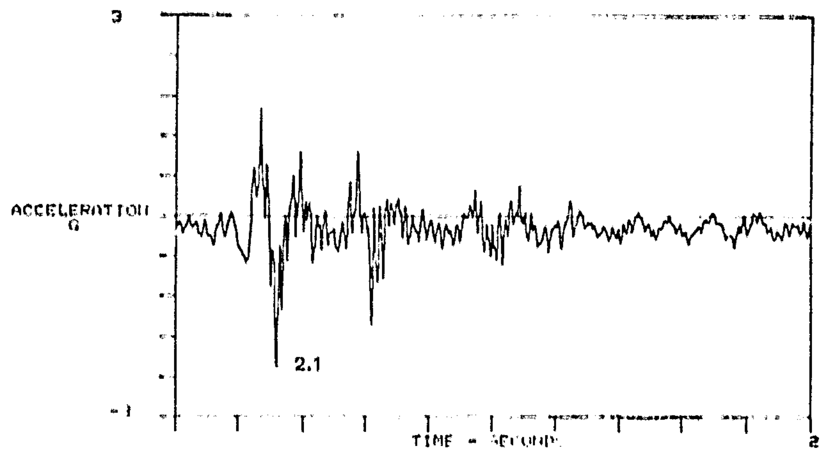


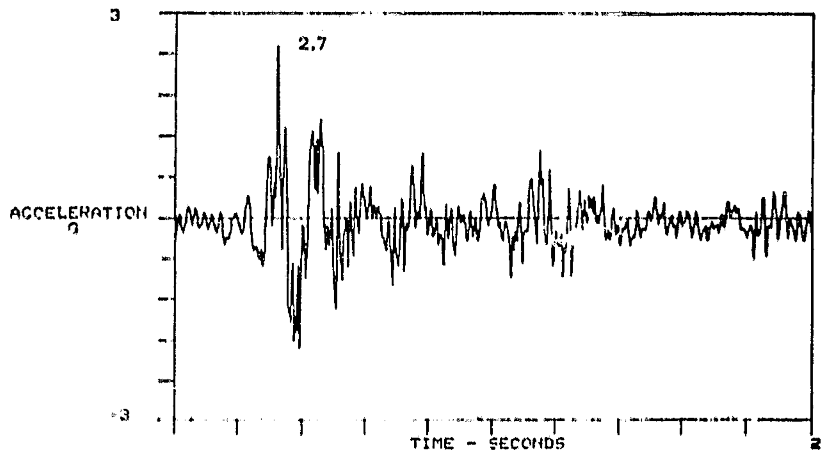
Figure 15. Accelerometer Time Histories with Increasing Gap Size (Accelerometer mounted on canister).

c.



GAS ENGINEERING VIB. TEST
RUN -10c
ACCELEROMETER 10Z
010 GAP BAY 2

d.



GAS ENGINEERING VIB. TEST
RUN -4c
ACCELEROMETER 10Z
NO SHIMS BAY 2

Figure 15. (continued)

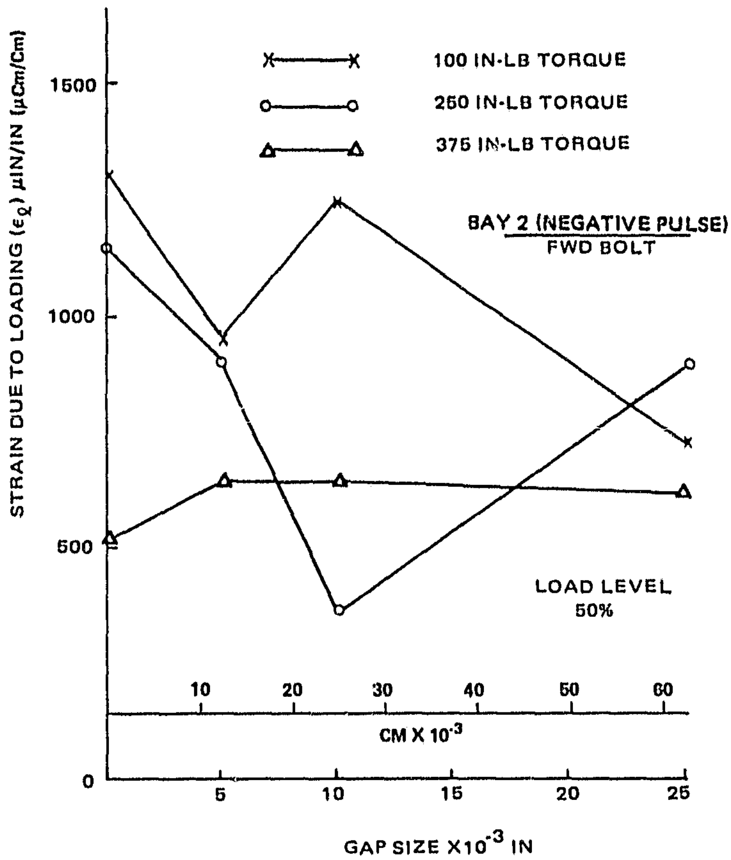


Figure 16. Variation of Strain due to Loading with Gap Size

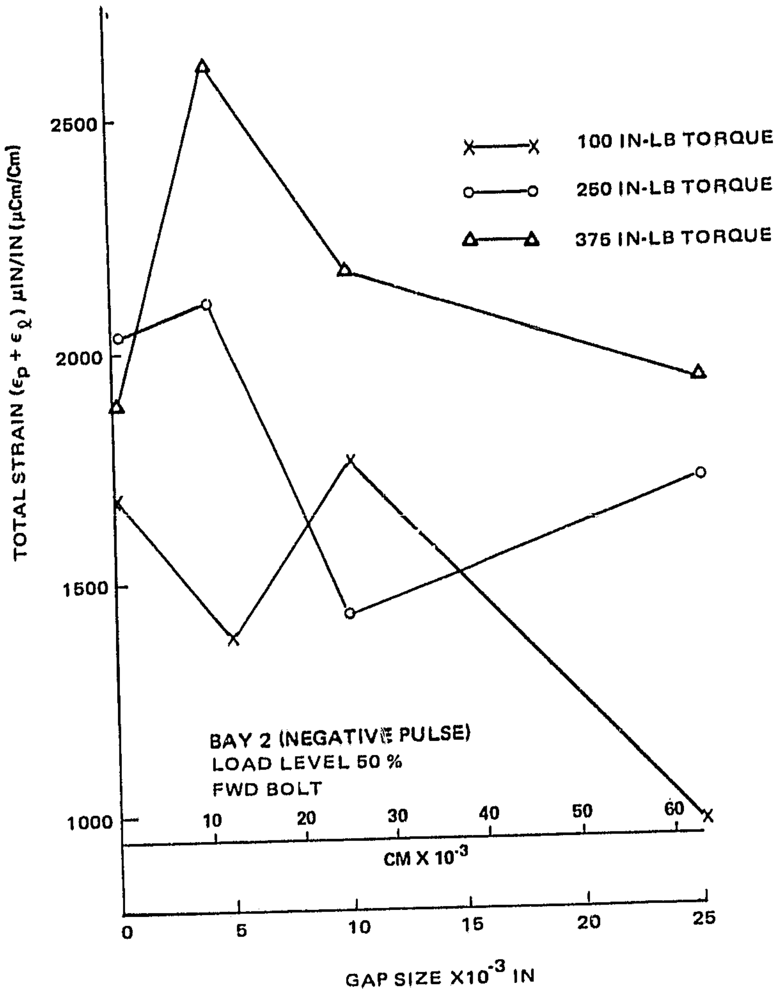


Figure 17. Variation of Total Strain with Gap Size

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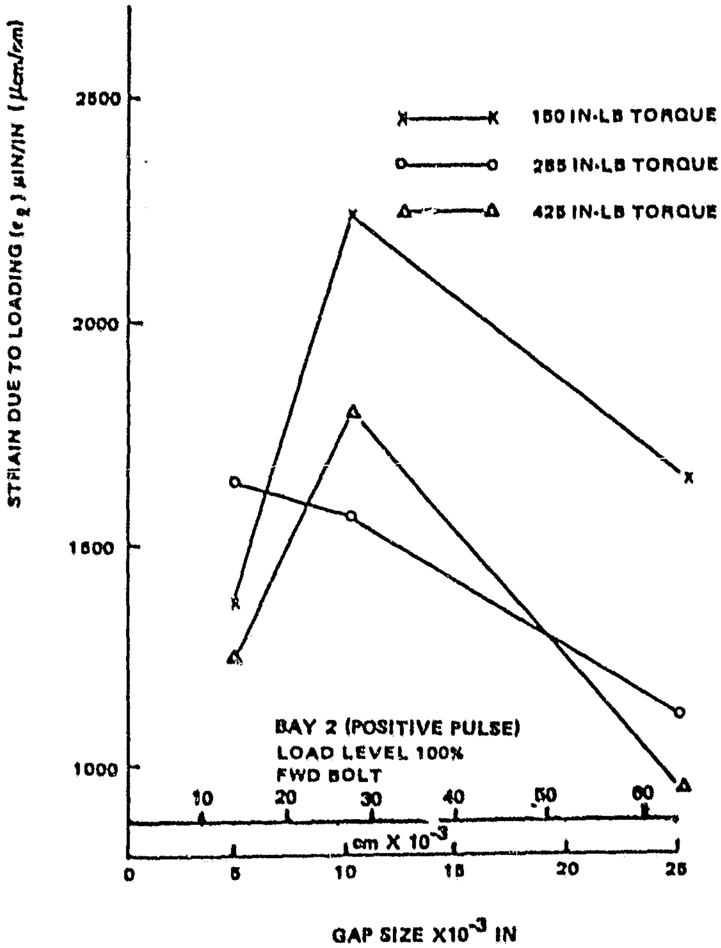

Figure 18. Variation of Strain due to Loading with Gap Size

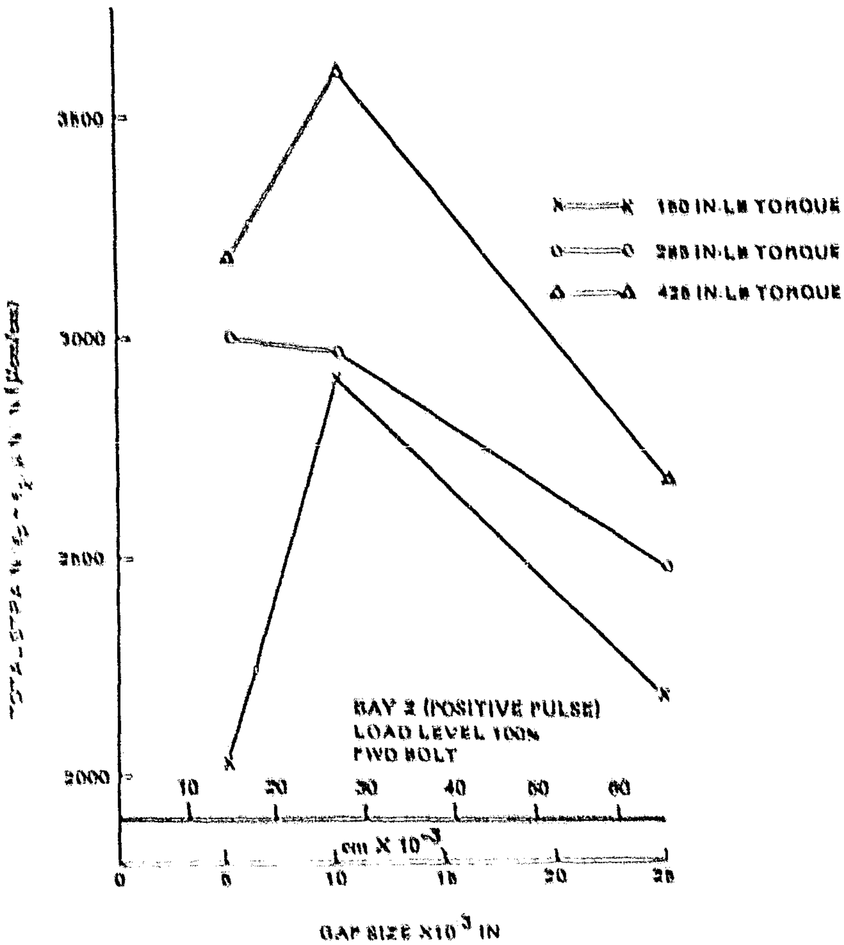

Figure 19. Variation of Total Strain with Gap Size

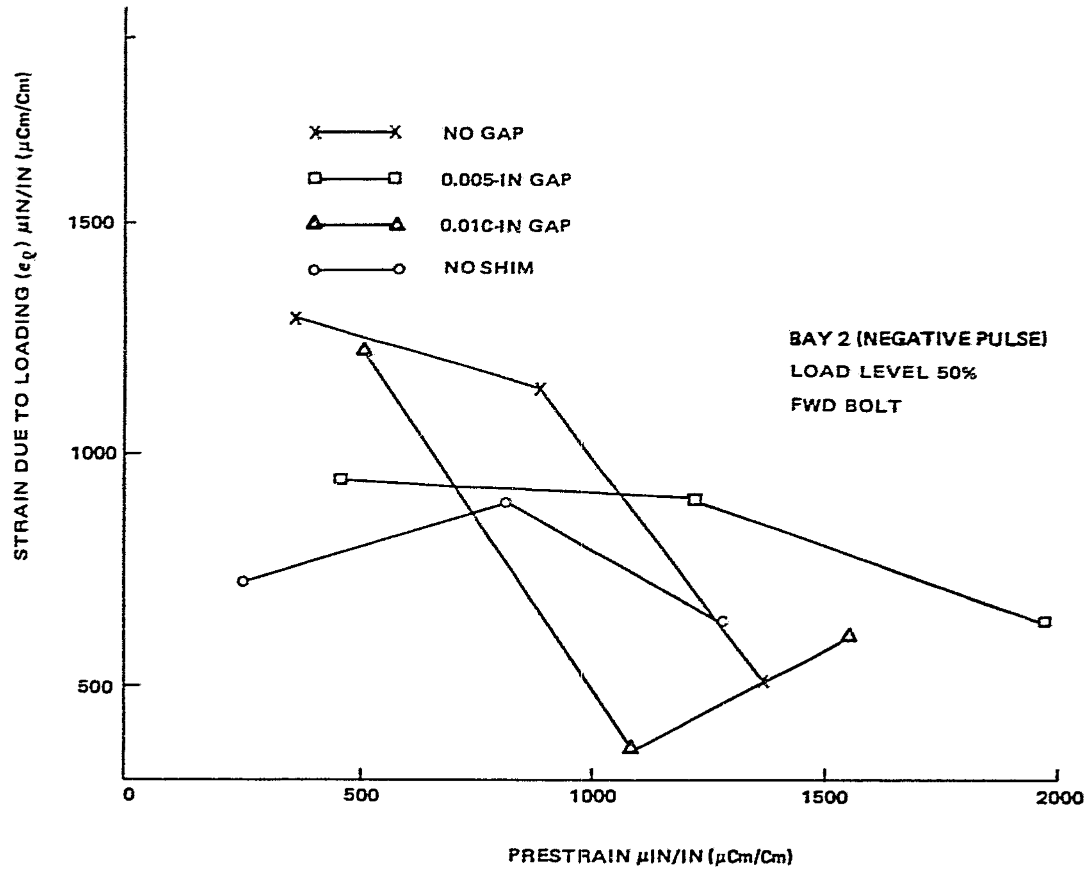

Figure 20. Variation of Strain due to Loading with Prestrain

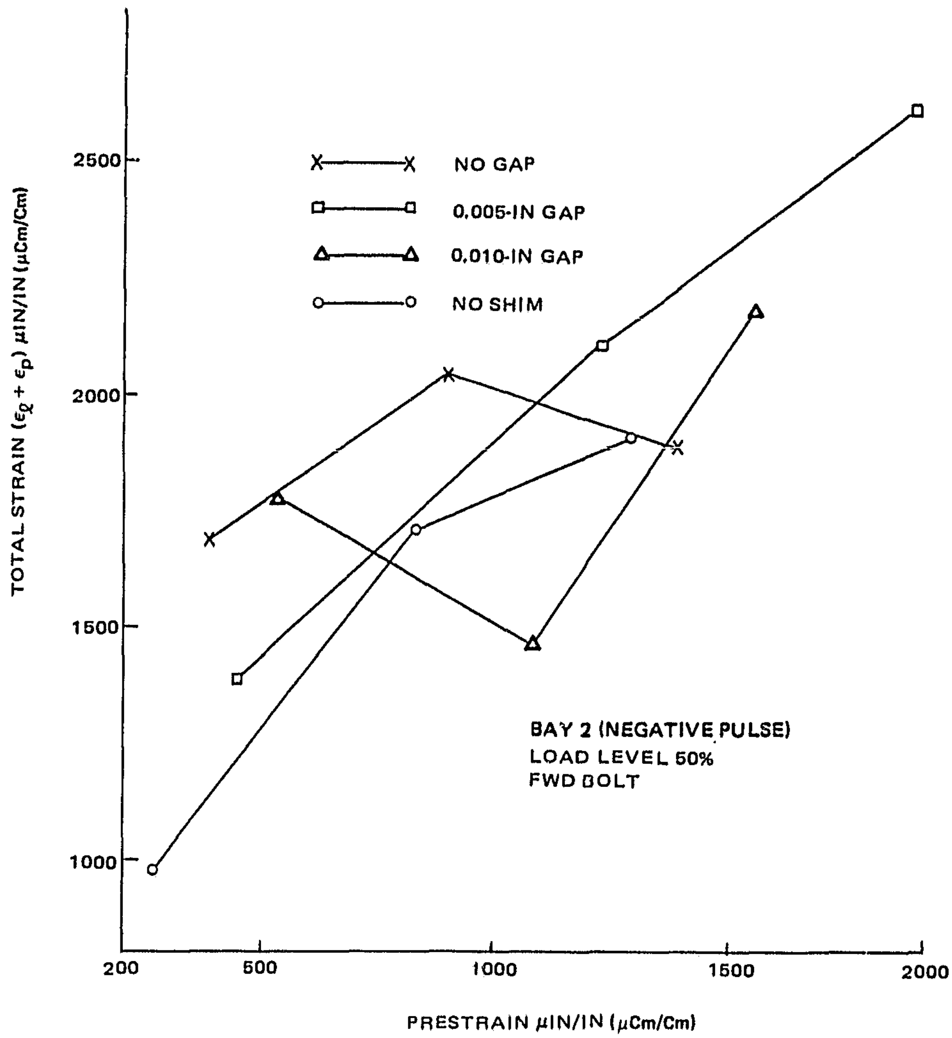

Figure 21. Variation of Total Strain with Prestrain

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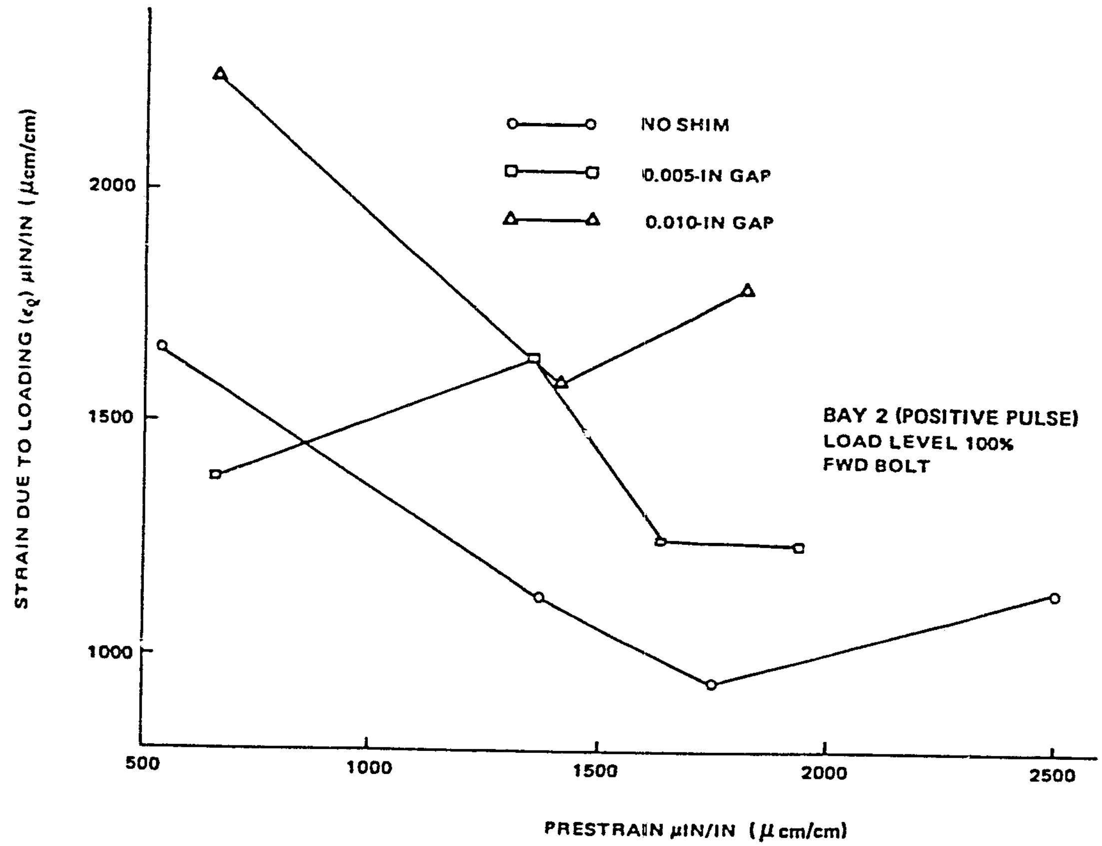

Figure 22. Variation of Strain due to Loading with Prestrain

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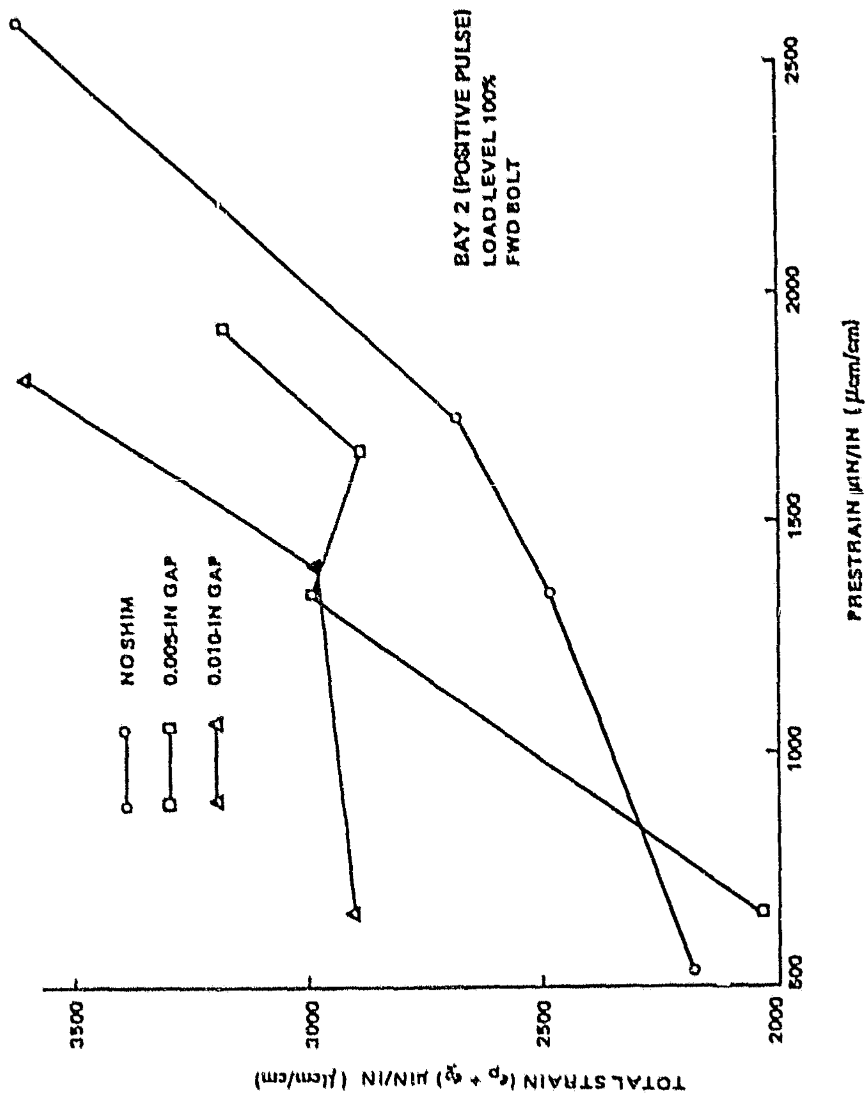

Figure 23. Variation of Total Strain with Prestrain

not reveal any deformation. Microscopic examination* was conducted on both the forward bolt which experienced the highest load and the aft bolt where the loading was well below yield. The examination did not indicate any yielding in either bolt. But, nuts for both these bolts had extensive flow on their bearing surfaces. This could be attributed to torquing or impacting because it has occurred for both nuts. Although the forward bolt experienced loading beyond its static yield strength, it did not really yield. This is probably due to the dynamic yield strength being higher than its static yield strength, and its notch strength being higher than the tensile strength.[6]

It should be noted that in the present investigation, the stiffness effect of the supporting structure on bolt strength has not been addressed. If the stiffness of the supporting structure is lower than that of the fixture used in the vibration tests, the loads imposed on the bolts could be higher.[3]

7. CONCLUSIONS

The following conclusions were made based on the test results:

- In all tests, the forward bolt experienced the highest strain levels. For some test conditions, stresses (calculated from measured strains) in the critical areas exceeded the static yield strength of the material, but microscopic examination showed no yielding in the bolt.
- No direct relationships have been found between gap size and strain levels in the bolt. Acceleration levels are higher with gap condition, but they do not translate to higher strains since they occur at higher frequencies. However, these higher accelerations could have an important effect on GAS payloads.
- With higher torque (prestrain), strains due to dynamic loading are somewhat lower. But, total strain increases with higher prestrain as with higher torque, the prestrain constitutes a major part of the total strain.

*Performed by Michael Barthelmy, Code 313.1, Goddard Space Flight Center.

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